Study on Green Development and Economic Development Evaluation of Shandong Provincial Capital Economic Circle

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Abstract. In the context of global climate change and intensified resource and environmental constraints, the coordinated advancement of green development and economic growth has become a core issue for regional sustainable development. This paper focuses on the Shandong Provincial Capital Economic Zone (Jinan City (A), Dongying City (E), Zibo City (C), Tai'an City (J), Liaocheng City (P), Binzhou City (M), Dezhou City (N)) as the study area. Based on panel data from 2013 to 2022, a dual-layer indicator system for green development and economic development is constructed. Using entropy value methods, coupling coordination degree models, and time-space analysis techniques, this study explores the coupling relationship and temporal-spatial characteristics of regional green development and economic development. The research findings indicate: (1) Over time, E's green development fluctuates downward, while A and C stabilize. M briefly recovers but then declines, and J, N, and P remain low for a long period. In terms of economic development, E maintains a high level with a slight increase, A and C steadily improve, while the other four cities remain at low levels. System coordination shows significant differentiation, with E consistently>0.75, A and C rising from 0.6-0.7 to 0.7-0.8, and M and the southwestern four cities consistently <0.6; (2) Spatially, green development exhibits a gradient distribution with higher levels in central and eastern regions and lower levels in southwestern regions. The economy centers around A, with C and E as secondary cores, and the other four cities being relatively weak; (3) All regions exhibit both high coupling degrees and moderate-to-low coordination degrees, reflecting the contradiction between "strong correlation and weak synergy" between green development and the economic system, which has become the core bottleneck constraining high-quality green development in the region. In response to the aforementioned issues, the study proposes implementing differentiated green development strategies and strengthening regional collaboration; promoting the construction of green industrial clusters and fostering new drivers of green growth; improving the green finance and technology innovation system to overcome resource and technological bottlenecks; empowering the application of green technologies through digitalization, enhancing systemic coordination efficiency, and providing practical pathways for regional green transformation.

Keywords: Green economy, provincial capital economic circle, coupling coordination degree, new and old kinetic energy transformation.

1. Introduction

In the context of global climate change and intensified resource constraints, the coordinated advancement of green development and economic growth has become a key issue for regional sustainable development. As the largest developing country, China faces dual challenges of economic transformation and ecological protection. The 20th National Congress of the Communist Party of China emphasized the need to balance economic growth with environmental protection and build a modern economic system. Shandong Province, as an industrial powerhouse, has been implementing the conversion of old and new growth drivers since 2018, promoting industrial upgrading and green innovation. The provincial capital economic zone, as the core area, holds a significant position in the Yellow River Basin strategy but faces prominent issues of uneven regional development. How to scientifically assess the interactive relationship between green development and economic development, reveal the mechanisms and obstacles of regional coordination, is crucial for resolving the contradiction between "economic growth and environmental pressure," facilitating the implementation of policies for the conversion of old and new growth drivers, and achieving high-quality coordinated regional development. This has important theoretical value and practical significance.

Current research consistently indicates that green technology innovation is a critical pathway to enhancing regional green development efficiency. It can achieve intensive and sustainable resource utilization by promoting technological progress and industrial structure upgrades [1-3]. Environmental regulation, as an institutional safeguard for green development, exhibits complex nonlinear characteristics in its incentive effects on green technology innovation, showing threshold effects or regional heterogeneity [4-5]. This is particularly evident in the Yellow River Basin, where the ecological environment is fragile and economic development faces pressure, making green development confront dual challenges of resource constraints and environmental pollution [6-7]. There is an urgent need to explore sustainable innovation-driven paths. In recent years, the rise of the digital economy has injected new momentum into green development. Studies show that digital technologies can optimize resource allocation, promote knowledge spillovers and industrial synergy, and accelerate the improvement of total factor productivity in green production [8-10]. Moreover, the implementation of regional coordinated development strategies and the deepening of mechanisms for transitioning from old to new growth drivers play an increasingly important role in coupling green development with high-quality economic development [11]. From a spatial perspective, there is also a significant spatial interaction effect between green development efficiency and industrial structure upgrading, forming a cross-regional green transition network [12]. In terms of research methods, many studies use coupling coordination degree models to analyze the synergistic relationship between the green development system and other systems [7-9], and apply spatial econometric models and obstacle degree models to identify regional heterogeneity and key constraints [3], providing a mature analytical framework for green development research.

In summary, existing research in the field of green development and economic growth synergy has shown characteristics of diverse elements and methods. However, current studies also have the following shortcomings: (1) there is a lack of specific exploration into the coordination between urban green development and economic development within regions; (2) research on the interaction mechanisms between green development and economic growth is limited, and the phased changes in actual cases have not been sufficiently discussed; (3) there is insufficient analysis combining specific regions where green development policies are implemented, making it difficult to provide support for optimizing policies tailored to local conditions. Based on this, this paper, taking into account the actual situation of the Shandong Provincial Capital Economic Zone, employs spatiotemporal analysis methods and coupling coordination degree models to deeply analyze the interactive relationship between green development and economic development and its spatial evolution characteristics, revealing their synergistic mechanisms and development paths, providing theoretical support and policy recommendations for regional green transformation.

2. Research area and research method

2.1. Overview of the study area

The Shandong Provincial Capital Economic Zone (35°38′N—38°43′N, 115°31′E—119°10′E) is located in the central-western part of Shandong Province. It refers to the urban cluster centered around Jinan City (the provincial capital), which radiates and drives the surrounding six prefecture-level cities: Dongying, Zibo, Tai'an, Liaocheng, Binzhou, and Dezhou (Figure 1). This area is one of the most economically active regions in Shandong, with the highest industrial concentration and population density. It bears the core function of transitioning from old to new growth drivers and promoting high-quality development across the province. The study area exhibits significant topographical gradient characteristics, with overall terrain sloping from west to east, from an altitude of 524 meters in western Jinan to-29 meters in eastern Dongying. The region has a well-developed water system, with rivers crisscrossing and mainly flowing northwest to southeast, providing abundant water resources for regional development. The total area of the region exceeds 60,000 square kilometers, with a permanent population of over 40 million people, encompassing diverse geographical features and economic foundations of Shandong Province.

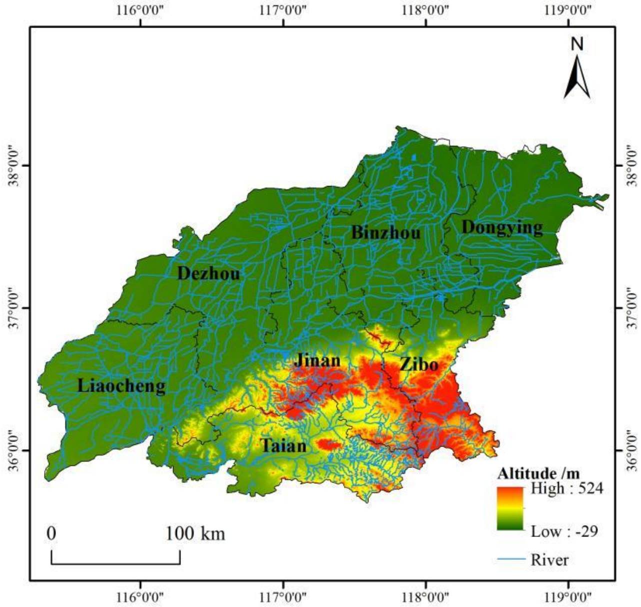

Figure 1. Overview of the study area

2.2. Indicator system construction

Table 1. Measurement and rating system of green development level in Shandong Provincial capital economic circle

Primary indicators	Secondary indicators	Specific indicators	Unit	Indicator attributes
Resource utilization	Water use efficiency	GDP per ten thousand yuan, water consumption	Cubic meter / 10,000 yuan	-
	Energy efficiency	Electricity consumption per ten thousand yuan of society	KWH / 10,000 yuan	-
Comprehensive ecological improvement	Pollutant discharge	Sulfur dioxide emissions per 10,000 yuan of secondary industry.	Ton/km	-
		Waste water discharge per ten thousand yuan in the secondary industry	Ton/km.	-
		The second industry per 10,000 yuan of smoke (powder) dust discharge	Ton/km	-
	Green investment	The proportion of energy conservation and environmental protection expenditures in the public financial budget.	Wan Yuan	+
Natural ecology	Ecological greening	Per capita park green space area	Square meter	+
	Urban green coverage	Green coverage rate of built-up areas	%	+
Economic development	Optimization of industrial structure	The proportion of the tertiary industry in GRP	%	+
	Level of investment in science and technology	The proportion of science and technology expenditure in the public financial budget	%	+
	Output per capita	Per capita GDP	Yuan	+
	Urban-rural gap	Per capita consumption expenditure of urban residents / per capita consumption expenditure of rural residents	%	-

This paper uses the "Shandong Statistical Yearbook" as its data source, adhering to the principles of scientificity, completeness, comparability, and operability in constructing an indicator system. It refers to relevant literature to build a dual-layer indicator system that covers both the green development system and the economic development system, as shown in Table 1. In the green development system, three dimensions—resource utilization, environmental governance, and natural ecology—are selected to reflect the city's performance in resource conservation, pollution prevention, and ecological protection; in the economic development system, dimensions such as total economic output, industrial structure, development efficiency, and technological innovation are chosen to demonstrate the city's economic strength, structural optimization level, and growth potential.

2.3. Research Methods

2.3.1 Entropy value measurement and weight calculation

This paper employs the entropy value method to perform weighted processing and comprehensive scoring of relevant indicators. The entropy value method is based on the principles of information theory, measuring the dispersion of indicators to reflect their importance in system evaluation: the greater the variation of an indicator, the smaller its information entropy, and thus the higher its weight in the comprehensive evaluation. Due to the inconsistent units of each indicator, standardization must be performed first, converting the original values into dimensionless relative values to eliminate the impact of unit differences. The calculation steps of the entropy value method are as follows:

(1) Standardized processing:

forward pointer:

$$Y_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \tag{1}$$

Negative indicators:

$$Y_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} \tag{2}$$

Among them, X_{ij} is the original value of the jth index in the i-th city, and Y_{ij} is the normalized value.

(2) Calculate the ratio of indicators:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{3}$$

Among them, P_{ij} represents the proportion of city i in index j, and n is the number of cities.

(3) Calculate information entropy:

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln(P_{ij}), k = \frac{1}{\ln(n)} \tag{4}$$

Among them, e_j represents the information entropy of the jth index, reflecting the uniformity of its distribution.

(4) Calculate redundancy (dispersion):

$$d_j = 1 - e_j \tag{5}$$

Redundancy d_j indicates the contribution degree of the jth index to the system information. The greater the redundancy, the more important the index is.

(5) Calculate the weight and get the comprehensive score.:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}, S_i = \sum_{j=1}^{m} w_j \cdot Y_{ij} \tag{6}$$

Among them, w_j is the weight of the jth index, and S_i is the comprehensive score of green or economic development in the i-th city.

2.3.2clustering methodology

In order to identify the heterogeneity of cities in the provincial capital economic circle in terms of green development and economic development level, this paper uses the system clustering analysis method to classify cities. The specific steps are as follows:

(1) Calculate the mean value of green development index and economic development index in each city during the research period (2013-2022), and form a two-dimensional eigenvector:

$$x_i = (\bar{G}_i, \bar{E}_i), i = 1,2, \dots, n \tag{7}$$

Among them, represents the $\bar{G}_i \bar{E}_i$ mean value of green development index of city i, represents the mean value of economic development index, and n is the number of cities.

(2) Secondly, the Z-score standardization method is used to standardize the feature matrix. $X = [x_1; x_2; \dots; x_n]$

$$Z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j} \tag{8}$$

Among them, x_{ij} represents the original value of the jth index in the i-th city, and μ_j and σ_j are the mean and standard deviation of the jth index respectively.

(3) Calculate the Euclidean distance between cities based on standardized data:

$$d_{ij} = \sqrt{\sum_{k=1}^{m} (Z_{ik} - Z_{jk})^2} \tag{9}$$

Among them, d_{ij} is the Euclidean distance between city i and city j, m is the number of indicators, Z_{ik} and Z_{jk} are the standardized values of the k_{th} indicator of city i and city j respectively.

Finally, the average connection method is used to systematically cluster the cities, construct the clustering tree, and divide the cities into several categories according to it, so as to identify their similar patterns in green and economic development.

2.3.3 Coupling coordination degree model construction

The coupling coordination degree model is an effective tool for measuring the degree of coordinated development between systems. This paper uses this model to quantitatively analyze the interactive relationship between urban green development and economic systems, revealing the characteristics of their coordinated evolution through coupling degree and coordination degree indicators. The model includes the following calculation steps:

(1) degree of coupling:

$$C = \frac{2\sqrt{G_i \cdot E_i}}{G_i + E_i} \tag{10}$$

Among them, C represents the coupling degree between the green development system and the economic development system, with a range of [0, 1]. The larger the value is, the closer the relationship between the two systems; G_i represents the comprehensive score of green development in city i; E_i represents the comprehensive score of economic development in city i.

(2) Comprehensive development index:

$$T = \alpha G_i + \beta E_i \tag{11}$$

Among them, T represents the comprehensive coordination index, reflecting the average level of the overall development of the two systems; α and β are the weights of the green development system and the economic development system respectively. In this paper, α=β=0.5 is taken, that is, it is considered that both are equally important.

(3) Coordination:

$$D = \sqrt{C \cdot T} \tag{12}$$

D represents the coupling coordination degree, which comprehensively reflects the degree of system coupling and overall development level. The higher the value is, the more significant the synergistic effect between green development and economic development is.

3. Result analysis

3.1. Analysis of regional green economy development characteristics

3.1.1 Cluster results

Based on the calculation of the mean values of green development index and economic development index for seven prefecture-level cities between 2013 and 2022, hierarchical clustering analysis was conducted using standardized Euclidean distance and weighted average methods to categorize the sample cities into four groups. As shown in Table 2, the first group includes only Dongying City. As a typical resource-based city, it stands out in both green development and economic development due to its strong capacity for green institutional response and ecological governance foundation, forming a significant "high-high" development characteristic. The second group includes Zibo City and Jinan City, both of which exhibit strong economic development capabilities and high levels of green development, showing a "moderately high-modern moderately high" development trend with a relatively balanced development structure. The third group is Binzhou City, which has relatively low average scores in both green and economic dimensions, indicating a "low-medium" development characteristic. The fourth group includes Tai'an City, Dezhou City, and Liaocheng City, all of which have limited transformation resources and low scores in both green and economic development, representing a "low-low" region.

Table 2. Cluster results of green economy development

Class	City
Category 1	Dongying City
Category 2	Zibo city, Jinan City
Category 3	Binzhou City
Category 3	Taian city, Dezhou City, Liaocheng City

3.1.2 Temporal evolution characteristics

Based on the time series data of green development index and economic development index (2013-2022), the changing trend of the four cluster categories in different years was analyzed.

As shown in Figures 2 and 3, in terms of green development, the first category of cities had a high starting point for green development, steadily improving from 2013 to 2015, reaching its peak in 2015, and then declining to around 0.6 in 2016. Although there was a recovery in growth afterward, it did not return to the previous high levels by 2022, indicating that they had certain advantages in the early stages of green development but experienced fluctuations during subsequent deepening processes. The second category of cities saw an overall upward trend in their green development index from 2013 to 2017, peaking in 2017, and then gradually declining year by year, demonstrating a gradual accumulation of momentum in the green transition. The third category of cities had a weak foundation for green development, with their green development index continuously declining from 2013 to 2016, hitting a low point in 2016, briefly rising from 2018 to 2021, but falling again in 2022, showing overall instability in green development. The fourth category of cities experienced an increase from 2013 to 2017, followed by a gradual decline after 2017, and showed a trend of recovery in 2022, indicating that green development has not formed a sustainable upward trajectory, reflecting relatively insufficient development momentum.

In terms of economic development, the first category of cities has maintained a high level of economic development index since 2013. Although there were slight fluctuations after 2016, it began to recover in 2021 and basically returned to its previous high in 2022, demonstrating strong economic recovery capabilities; the second category of cities has seen relatively stable economic development since 2013, reaching a peak in 2019. Despite some fluctuations, it has remained at a high level; the third category of cities has experienced significant fluctuations in its economic development index. It developed slowly from 2013 to 2016, showed a certain degree of recovery before 2021, but fell again in 2022, indicating an unstable economic development process; the fourth category of cities had the lowest starting point for economic development, which rapidly increased in 2015 but remained low until 2022, showing weak foundations and insufficient momentum.

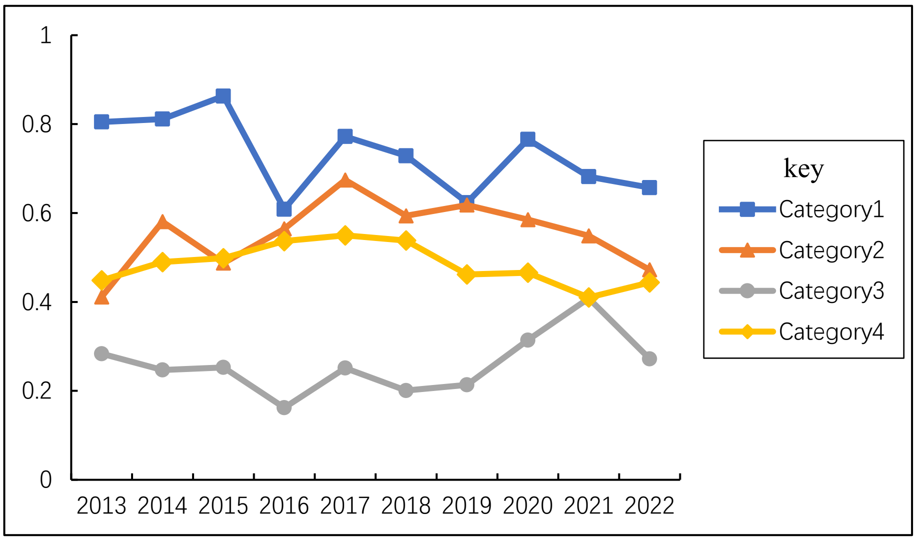

Figure 2. Change of green Development Index (2013-2022)

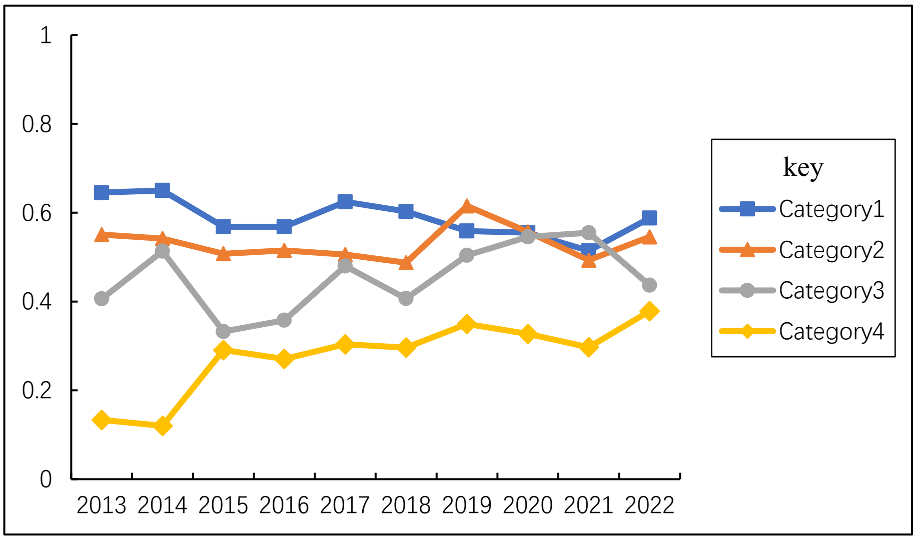

Figure 3. Change of urban economic development index (2013-2022)

3.1.3 Spatial distribution pattern

In this part, the geographical distribution characteristics of green development and economic development scores in provincial capital economic circle are visualized by spatial analysis method to reveal their spatial agglomeration and differentiation.

As shown in Figure 4, the green development level of Shandong Province's capital economic zone exhibits a spatial pattern characterized by "high in the central region, strong in the eastern region, stable in the northern region, and weak in the southwestern region." Specifically, Dongying City and Zibo City, located at the junction of Central Shandong and Northern Shandong, close to the Yellow River Delta and the Bohai Rim area, have had their green development index consistently at the "moderate" to "high" level. Jinan City, as the provincial capital, situated at the regional center, possesses political, economic, and ecological radiation functions, placing its green development index among the top in the provincial capital economic zone. In contrast, Liaocheng City in the southwestern part and Tai' an City in the southern part have lower green development indices, long remaining at the "low" and "very low" levels. These regions, located on the periphery of Shandong, are constrained by terrain, industrial path dependence, and infrastructure limitations, leading to relatively lagging progress in green development, making them "valleys" in the province's overall green development landscape. This indicates significant shortcomings in ecological governance capabilities, support from green industries, and efficiency in technology transfer. Dezhou City and Binzhou City in the northern region, situated in the transition zone from the Yellow River estuary to the Northern Shandong Plain, have a mid-level green development level but show a noticeable gap compared to Dongying City and Jinan City, suggesting that Dezhou City and Binzhou City have yet to fully unleash their green development potential, presenting a spatial trend of "stability in the mid-range."

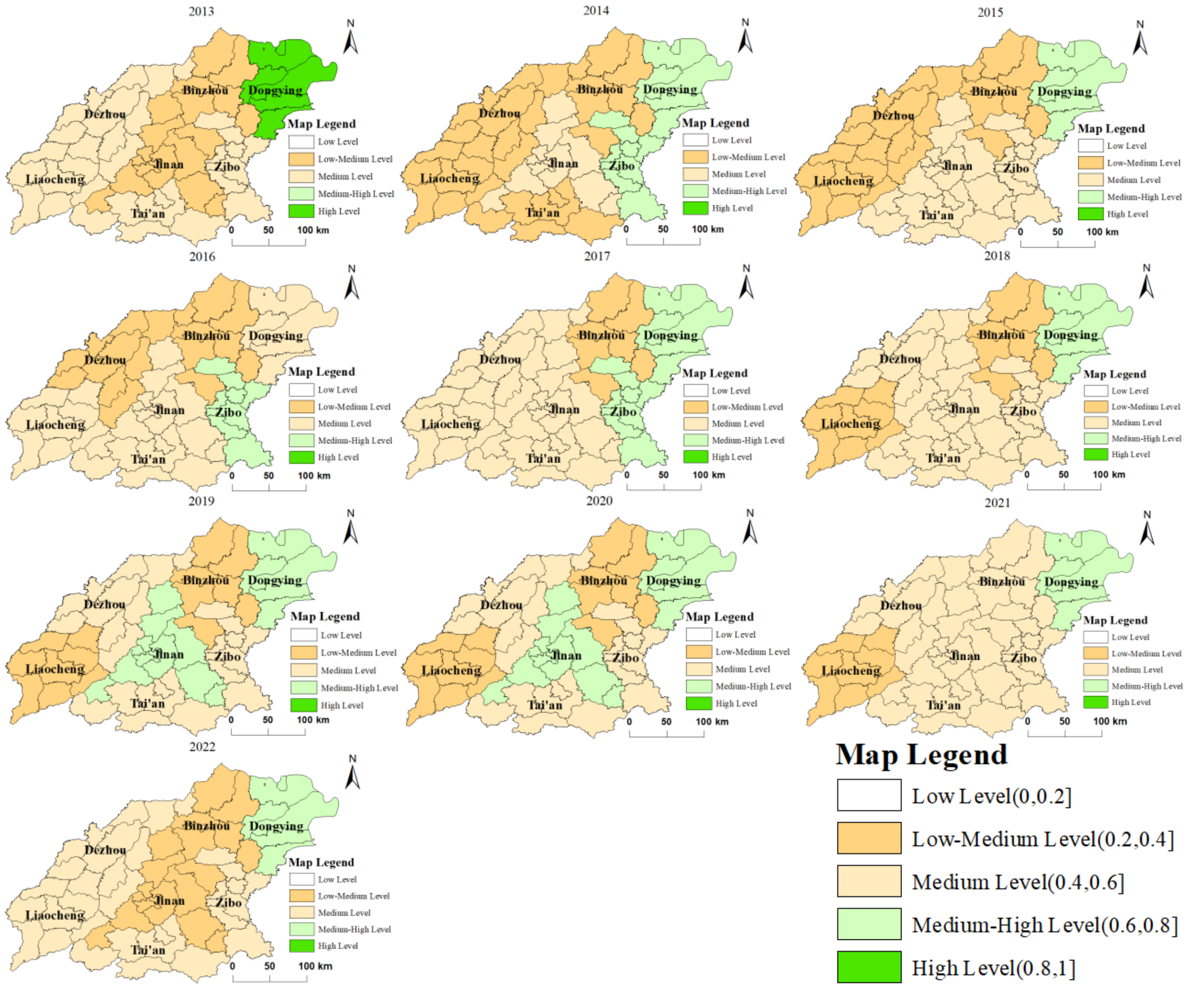

Figure 4. Map of green development level measurement in each city

As can be seen from Figure 5, the level of regional economic development presents a significant spatial differentiation pattern of "strong east and weak west, slow south and rapid north", and shows a spatial evolution trend from "axial distribution" to "core expansion" in the past ten years. The regional economic development presents obvious polarization characteristics and gradient diffusion effect.

From an overall spatial distribution perspective, the economic development levels of the seven cities in Shandong Province's provincial capital city cluster exhibit a distinct characteristic of "central leadership, relatively strong in the east and central regions, and weaker in the west." Jinan City, as the core city of the province, has consistently maintained a high or high-level status, playing a pivotal role as a regional economic growth pole. Zibo City and Dongying City, leveraging their industrial foundations and resource advantages, also perform relatively well economically, with Dongying City showing a sustained upward trend in recent years. In contrast, Dezhou City, Liaocheng City, and Tai'an City generally have lower to medium-level development, with insufficient economic vitality and relatively weak development momentum, leaving room for enhanced interaction with the regional core.

From the perspective of internal structural differences, there is a significant imbalance in economic development within provincial capital economic zones. Jinan City's high-level development status forms a clear gradient gap with surrounding cities, showing a pattern where economic radiation from Jinan to neighboring cities gradually diminishes. Tai'an City has consistently remained at a relatively low level in measurement results, demonstrating stable but not prominent growth trends. Zibo and Dongying Cities have alternated as secondary core cities in some years, with their layouts in high-tech manufacturing and resource-based industries playing a strong driving role. In contrast, Liaocheng City and Binzhou City experience greater fluctuations in economic development levels, lacking a solid foundation for stable growth, and still need to improve internal regional development coordination.

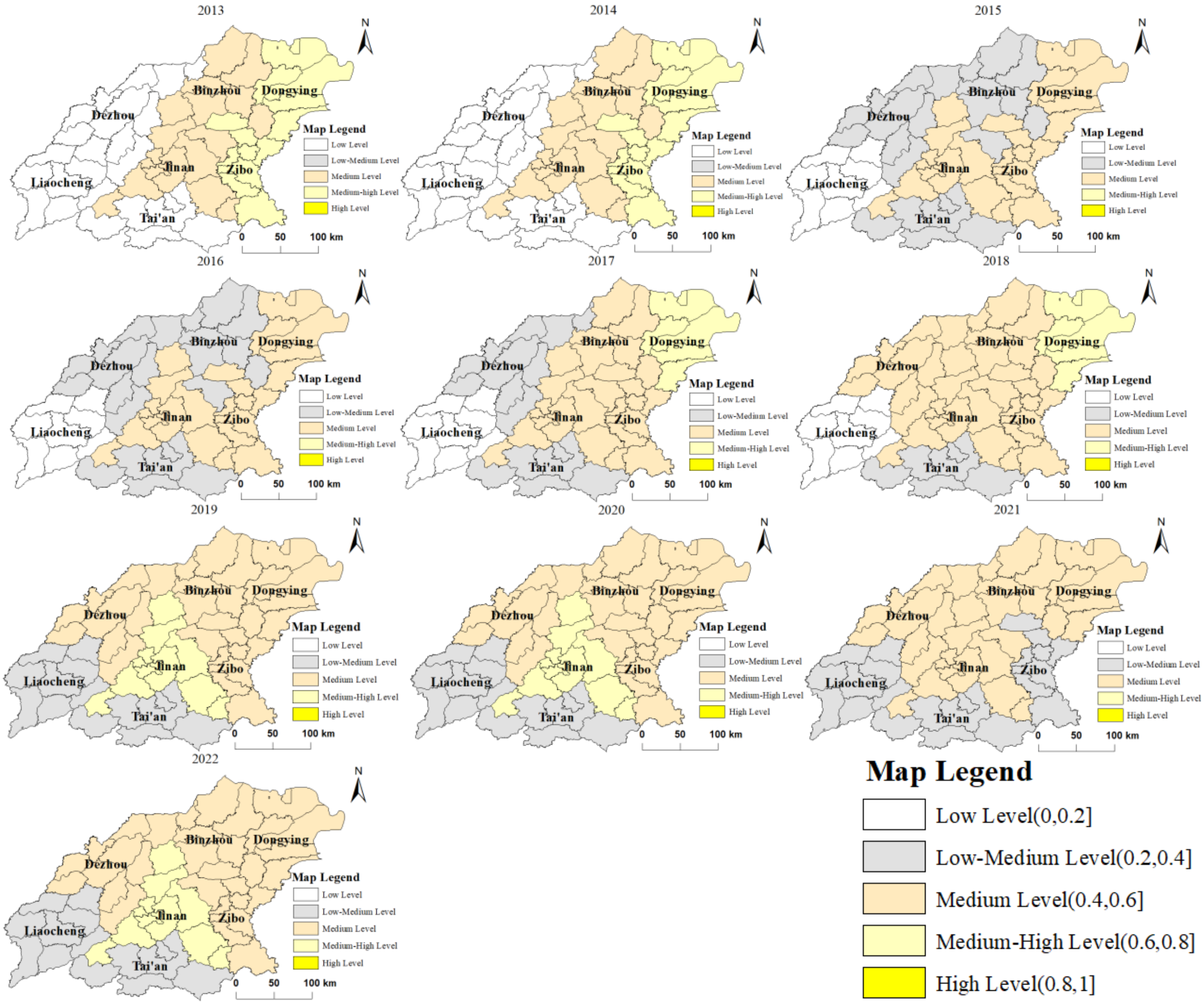

Figure 5. Map of economic development level measurement of each city

3.2. Evaluation of the coupling and coordination between green development and economic development in provincial capital economic circle

As can be seen from Table 3, based on the coupling coordination degree model, the coupling relationship between the green development and economic development system of the seven cities in Shandong Provincial capital economic circle from 2013 to 2022 was measured. The seven cities showed a basic situation of high coupling, medium coordination and regional differentiation as a whole.

Table 3. Calculation results of coupling coordination degree in each city

Year	Jinan City		Dongying City		Zibo City		Tai'an City	
	C	D	C	D	C	D	C	D
2013	0.9931	0.6353	0.9939	0.8489	0.9864	0.7402	0.8613	0.5351
2014	0.9950	0.6832	0.9939	0.8522	0.9999	0.8083	0.8543	0.5653
2015	0.9999	0.6891	0.9786	0.8369	0.9996	0.7212	0.9488	0.6675
2016	0.9999	0.6963	0.9994	0.7670	0.9961	0.7695	0.9554	0.6472
2017	0.9944	0.7305	0.9888	0.8310	0.9602	0.7862	0.8697	0.6648
2018	0.9998	0.7103	0.9955	0.8141	0.9859	0.7540	0.9129	0.6521
2019	0.9990	0.8242	0.9985	0.7682	0.9981	0.7433	0.9490	0.6466
2020	0.9990	0.7617	0.9978	0.8467	0.9999	0.7449	0.9417	0.6300
2021	0.9974	0.7424	0.9901	0.7695	0.9807	0.6928	0.9580	0.5927
2022	0.9692	0.7163	0.9985	0.7884	0.9931	0.6966	0.9855	0.6319
Year	Dezhou City		Binzhou City		Liaocheng City			
	C	D	C	D	C	D		
2013	0.9261	0.5370	0.9841	0.5826	0.5835	0.3658		
2014	0.8347	0.5160	0.9366	0.5967	0.5562	0.3512		
2015	0.9998	0.6265	0.9907	0.5385	0.8764	0.5309		
2016	0.9961	0.6100	0.9264	0.4908	0.8058	0.5675		
2017	0.9958	0.6435	0.9024	0.5744	0.8012	0.5343		
2018	0.9999	0.6602	0.9408	0.5347	0.8663	0.5507		
2019	0.9934	0.6598	0.9144	0.5728	0.9713	0.5731		
2020	0.9982	0.6916	0.9631	0.6435	0.9916	0.5350		
2021	0.9983	0.6535	0.9883	0.6899	0.9890	0.5132		
2022	0.9902	0.6890	0.9727	0.5871	0.9610	0.5786		

In order to further analyze the coordination relationship between the systems, this paper draws a radar chart based on the coupling coordination degree results, so as to visualize and compare the coordination level among different indicators.

As shown in Figure 6, the coupling degree of various cities is generally high, but there are significant differences in coordination levels, and both exhibit different trends over time. Based on the characteristics of coupling and coordination degrees over the past decade for each prefecture-level city, cities are categorized into three types: (1) High-quality Synergy Type: Dongying City; (2) Development Enhancement Type: Jinan City, Zibo City; (3) Lagging Improvement Type: Liaocheng City, Tai'an City, Dezhou City, Binzhou City.

Specifically, the coupling degree of Dongying City remained above 0.9 from 2013 to 2015, with the coupling degree line segment positioned at the outermost side of the radar chart, indicating that its green development system and economic development system were closely linked from the beginning. From 2016 to 2018, when some cities experienced fluctuations in their coupling and coordination degrees, Dongying City maintained a stable trend. Although there were slight fluctuations in its coupling degree, it consistently remained within a high-level range, and its coordination degree also consistently stayed at a good or better level. By 2019 to 2022, Dongying City's coupling and coordination degrees continued to remain at high levels, demonstrating that its green economic development strategy has good sustainability.

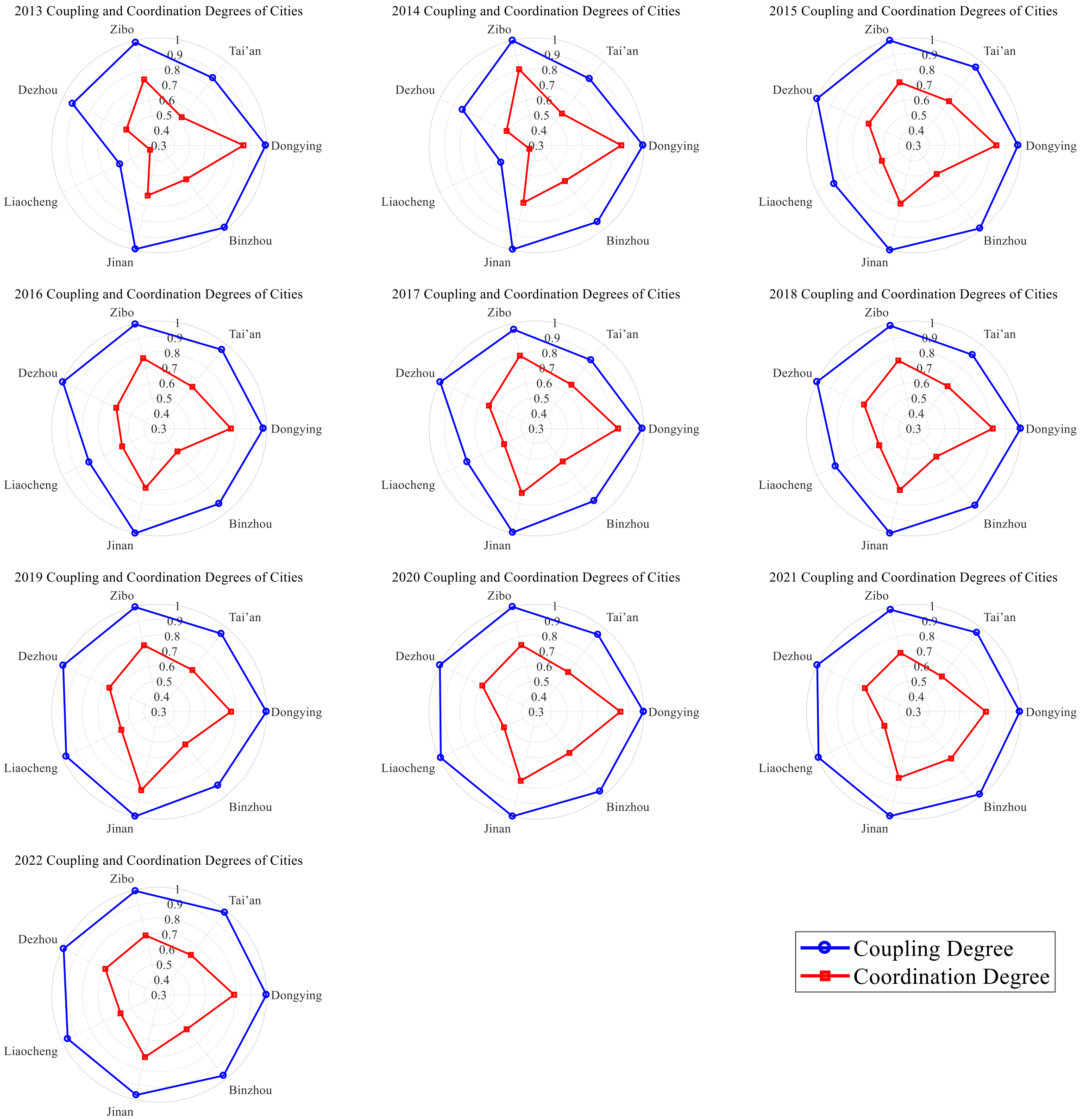

Figure 6. Radar chart of coupling coordination degree of each city (2013-2022)

Jinan City had a high coupling degree during the period of 2013-2015, but its coordination degree was relatively limited, with a short red coordination line segment. During this phase, Jinan City may have been in the early stage of gradually integrating economic restructuring with green development concepts. Although there was already some connection between the two systems, their coordinated development was still insufficient. From 2016 to 2018, Jinan City vigorously promoted industrial structure adjustment and increased investment in green development, further enhancing the coupling degree and steadily increasing the coordination degree, with the red line segment gradually extending. From 2019 to 2022, Jinan City continued to advance green industry development and energy conservation efforts, maintaining a high coupling degree and achieving a significant improvement in the synergy between green development and economic growth. Zibo City had a high coupling degree during the period of 2013-2015, but its coordination degree showed a downward trend. From 2016 to 2018, through measures such as promoting industrial greening and strengthening technological innovation, Zibo City further enhanced its coupling degree, with the coordination degree gradually rising and stabilizing. By 2019-2022, the coupling degree and coordination degree structure of Zibo City were basically established, maintaining above 0.9 and 0.7, respectively.

During the period from 2013 to 2015, the coupling and coordination levels of Liaocheng City, Tai'an City, Dezhou City, and Binzhou City were generally low, indicating poor overall performance. This suggests that the synergy between regional green development and economic systems is insufficient, and there is a lack of intrinsic motivation for industrial green transformation. Between 2016 and 2018, the coupling degree of some cities improved, with Tai'an City showing particularly significant progress. However, the overall improvement in coordination was limited, and the coupling degree of Dezhou City exhibited certain fluctuations. By 2019 to 2022, although all four cities implemented relevant optimization measures, both coupling and coordination levels showed an upward trend. Nevertheless, the overall level has not yet reached an ideal state, and there remains a considerable gap compared to advanced cities that have achieved high integration of green development and the economy. These phenomena indicate that the four cities still face numerous challenges in promoting the coordinated integration of green development and economic systems, and there is an urgent need to enhance the systematic nature and implementation of policies, as well as accelerate the process of green transformation and upgrading of industrial structures.

4. Discussion

4.1. Analysis of regional green development differences and causes

The level of green development within the Shandong Provincial Capital Economic Zone shows significant spatial differences. Cities like Dongying have long been at a high level of green development, thanks to their sensitivity in responding to green policies and the rigidity of policy implementation as resource-based cities; although Jinan is a core city in the region, its performance in green development is average, reflecting increased environmental pressure under rapid urban expansion; meanwhile, places like Liaocheng and Zibo are constrained by weak ecological foundations and strong fiscal constraints, leading to slow progress in green development.

The causes of the green development differences in the aforementioned regions can be categorized into three types: First, differences in economic development stages, where cities with a solid economic foundation have greater capacity to allocate green development resources; Second, resource endowment heterogeneity, where Dongying leverages its excellent ecological reserves and high green investment capabilities to establish regional advantages; Third, the policy response capability and institutional execution ability of local governments, which are key factors in enhancing the level of regional green development [13].

4.2. Practice and Challenges of the Transformation of old and new growth drivers

In recent years, the economic zone of Shandong Province's capital has accelerated the integration of industrial structure optimization and green development during the transition from old to new growth drivers. It actively promotes the exit mechanism for high-energy-consuming and highly polluting industries, building clusters of emerging industries such as clean energy, intelligent manufacturing, and new materials. Empirical results show that places like Dongying and Zibo have achieved a high degree of coupling between green development and economic development as the proportion of high-tech industries increases.

However, there are still many challenges in the transition from old to new growth drivers. First, traditional growth drivers have strong inertia and significant resistance to green transformation, which affects Zibo's industrial path dependence and hinders the advancement of green development. Second, the effectiveness of green growth conversion is uneven, with widening disparities between regions, evident in significant differences in coordination. Third, support elements such as green finance and green talent remain insufficient, and some small and medium-sized cities lack systematic innovation support and external capital guidance, leading to inadequate momentum for nurturing new green growth drivers.

4.3. Impact and enlightenment of green development on economic development

Green development is not only an environmental constraint but has increasingly become a significant driving force for sustainable economic growth. This study shows that the steady improvement in the Green Development Index has promoted the activation of economic systems in most cities. Taking Dongying City as an example, its green development advantages have strongly supported the development of high-value-added industries and improved resource allocation efficiency, achieving a positive synergy between "green empowerment" and economic growth. However, in cities like Liaocheng and Binzhou, there remains a mismatch between the green development system and the economic development system, indicating that without industrial transformation and innovation checks, the ability of green development to drive high-quality economic growth will be somewhat hindered.

4.4. Synergistic development path of emerging technologies and green transformation

Emerging technologies are gradually becoming a crucial tool for driving the green transition. In the development of provincial economic zones, digital intelligence, big data, and the Internet of Things are widely applied in pollution control, energy scheduling, ecological monitoring, and other fields, effectively enhancing the efficiency of green governance and the precision of system operations. The policy implementation capabilities and technical application abilities of local governments play a vital role in promoting the development of green technologies. Especially when local governments formulate targeted policy incentives and technical application guidance, emerging technologies within the region can more efficiently align with the needs of the green transition, thereby promoting sustainable regional development [14]. The coordinating role of local governments in advancing the green transition, particularly in the synergy between technological innovation and policy support, further strengthens the integration of green development and emerging technologies.

5. Conclusion and countermeasures

5.1. Research conclusion

Based on the green development data of cities in Shandong Provincial Capital Economic Circle, this paper deeply analyzes the level of green development, the coordination between economic growth and environmental protection, and the main obstacles affecting green development. Through the systematic analysis of data from 2013 to 2022, the following main conclusions are drawn:

(1) The level of green development has steadily improved but there are regional differences. During the study period, the overall level of green development in Shandong Province's capital economic zone has increased, but there are significant disparities in green development levels among cities. Cities like Dongying and Jinan have performed well; however, cities such as Liaocheng and Binzhou still face considerable bottlenecks in green development and lag behind.

(2) The synergy between green development and economic growth is gradually increasing. As green development policies are further implemented, most cities exhibit positive interactions between green development and economic growth. In Jinan and Dongying, green development has become a significant driver of economic growth. However, in some cities with weaker economic foundations, the coupling degree between green development and economic growth remains low, indicating that the transition to green development and economic growth have yet to achieve optimal balance.

(3) The main obstacles to green development exhibit diversity, with varying factors in different cities. Resource-based cities like Dongying face significant pressure in industrial restructuring and environmental pollution control, while some cities, due to fiscal constraints and insufficient technological innovation capabilities, have failed to effectively promote green development. These differences in obstacles lead to uneven progress in green development.

5.2. Policy recommendations

(1) Strengthen differentiated strategies for regional green development and tailor green development paths to local conditions. There are significant differences in the level of green development among cities within the provincial capital economic circle. Cities like Jinan and Dongying, with better foundations, should continue to play a leading role in green development, increase investment in green technology research and development, optimize the layout of green industrial chains, and build highlands for green economic development. Resource-based cities such as Dongying should focus on both industrial structure adjustment and ecological environment restoration, accelerating the green transformation of resource-based industries. In contrast, cities with weaker foundations in green development, such as Liaocheng and Binzhou, should prioritize improving green infrastructure, enhancing environmental quality, actively introducing green technologies and projects, and boosting their capacity for green development.

(2) Promote the deep integration of green development and economic growth. Green development should not be separated from economic development but should become a new driving force for high-quality regional economic growth. Efforts should be made to vigorously promote the construction of green industrial clusters, focusing on developing strategic emerging industries such as green manufacturing, new energy, and environmental protection equipment, enhancing the market competitiveness and agglomeration effect of green industries. At the same time, through policy guidance and financial support, traditional industries should be guided to transform towards cleaner and lower-carbon directions, improving the green supply chain management system to achieve comprehensive penetration of green elements into the economic system. Additionally, the green consumer market should be vigorously developed by fostering green consumption concepts, strengthening the certification and promotion of green products, stimulating the potential of green domestic demand, and providing sustained impetus for the development of the green industry.

(3) Targeted breakthroughs should be made to overcome the main obstacles to urban green development, enhancing the resilience of green development. For cities facing tight fiscal resources and insufficient green investment, it is necessary to accelerate the construction of a green financial system. This can be achieved through green loans, green bonds, carbon finance, and other means, guiding social capital towards green sectors and lowering the financing threshold for green projects. In cities with weaker technological innovation capabilities, efforts should focus on deepening the integration of industry, academia, and research, building a green technology innovation system with enterprises as the main body and universities and research institutions as support, accelerating the transformation and implementation of green technologies. At the same time, local governments' ability to formulate and implement green policies should be enhanced, improving the foresight and execution of these policies.

(4) Green technology is the core driver of ecological economic transformation. Efforts should be made to strengthen the construction of green technology platforms, promoting collaborative research and scenario application of key green technologies such as intelligent manufacturing, energy conservation and environmental protection, and renewable energy. Digital transformation can significantly enhance the application effectiveness of green technology [15]. By integrating IoT, big data, and AI in areas like green city management, energy scheduling, and pollution monitoring, we can achieve the evolution of green technology towards intelligence and systematization. The government can establish demonstration projects and procurement mechanisms for green technology to provide an application platform for green technology enterprises, facilitating the rapid dissemination of green technological achievements.

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